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Technical Report on Seismology No. 25

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Mantle Rayleigh Waves from the Kamchatka Earthquake of 4 November 1952

by

Maurice Ewing and Frank Press

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ABSTRACT

Mantle Rayleigh waves from the Kamchatka earthquake of 4 November 1952 are analyzed. The new Palisades long period vertical seismograph recorded orders R6 - R15, the corresponding paths involving up to 7 complete passages around the earth. The dispersion data for periods below 400 sec are in excellent agreement with earlier results and can be explained in terms of the known increase of shear velocity with depth in the mantle. Data for periods 400-480 sec indicate a tendency for the group velocity curve to level off, suggesting that these long waves are influenced by a low or vanishing shear velocity in the core. Absorption studies indicate a value $1/Q=370 \times 10^{-5}$ for the internal friction in the mantle at periods 250-350 sec. This is a little over half the value reported earlier for periods 140-215 sec.

INTRODUCTION

In a previous paper[1] an investigation of amplitudes and dispersion of mantle Rayleigh waves was presented using data from three earthquakes recorded on the Pasadena linear strain and Benioff seismographs. Rayleigh waves in the period range 1-7 minutes involving paths with as many as three circuits of the earth (R2 - R7) were described. Orbital motion proper for Rayleigh waves was demonstrated and a group velocity curve of high precision was deduced and accounted for in terms of mantle structure. Analysis of the amplitudes led to values of internal friction in the mantle for periods of 140 and 215 sec.

A little over a year ago a special long period vertical seismograph (To=15 sec, Tg=90 sec) was placed in operation at Palisades for the purpose of recording mantle Rayleigh waves and other long period oscillations. The instrument was quite sensitive, allowing for operation with a highly overdamped pendulum and galvanometer, yet with sufficient magnification to record at the limit imposed by microseisms. Response to long period oscillations was improved in this way. It was found necessary to maintain the instrument at constant temperature as well as to provide buoyancy compensation

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1. Maurice Ewing and Frank Press, "An Investigation of Mantle Rayleigh Waves", Technical Report on Seismology No. 23, also in press Bull. Seism. Soc. Amer.

for the pendulum so that spurious oscillations originating in atmospheric pressure fluctuations[2] could be removed. A more complete report on the seismograph will be presented separately.

On November 4, 1952 a large earthquake occurred on Kamchatka. B.C.I.S. gives for epicentral data 52.9°N, 160.1°E, H=16-58-23 and Pasadena magnitude was 8 1/4. The Palisades instrument recorded mantle Rayleigh waves or orders R6 - R15, the corresponding paths involving as many as 7 complete passages around the earth. Earlier orders were off scale and could not be read. The Pasadena linear strain seismograph wrote an excellent record of R1, R2 and R4. These long period oscillations, continuing for more than 20 hours after the instant of the shock, could be positively identified with the proper order of mantle Rayleigh wave by use of the dispersion curve derived in the earlier paper.[3]

The new data presented in this paper is highly significant in that it extends the observed propagation distances of mantle Rayleigh waves to 288,370 km, provides additional points for the group velocity curve with a suggestion that the trend of the curve for periods longer than 400 sec is influenced by the core, and supplies an additional

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2. Maurice Ewing and Frank Press, Further Study of Atmospheric Pressure Fluctuations Recorded on Seismographs, Trans. Amer. Geophys. Union, in press 1953.

3. See footnote 1.

value for the internal friction of mantle rocks for periods 250-350 sec.

DATA

The original Palisades long period vertical seismogram appears in Figure 1. Various orders of mantle Rayleigh waves are indicated by arrows. The short period crustal Rayleigh waves from the numerous after shocks often occur riding on the longer period mantle oscillations of the main shock, making record reading difficult at these times.

The method of analysis is similar to that described in detail in the previous paper[4] and only the results will be given here.

Table I lists arrival times, travel times and velocities for the different periods observed in each order of mantle Rayleigh waves. The results are presented graphically in Figure 2 where group velocity is plotted as a function of period. Data from our previous paper are included. It can be seen in Figures 1 and 2 that only R6 exhibits both the long period and short period branch representing respectively trains of waves whose periods decrease and increase with time, the two trains merging finally in the Airy phase at the minimum value of group velocity. Although the short period branch of R2 alone is listed, there is a slight but definite indication of a long wave on the Pasadena seismogram. Accurate reading of the

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4. See footnote 1.

period is made difficult by the insufficient separation of the long waves at this short propagation distance. Similarly R1 appears only as a long period pulse, the propagation distance being too small for any dispersive separation of the component waves. The remaining orders R7 - R15 appear only as waves corresponding to the long period branch, the propagation distances becoming so large as to lose the shorter period oscillations through their higher absorption.

The new data reaffirms the earlier conclusion[5] that a single dispersion curve represents all the orders and that there is no systematic departure with increasing length of path. It was also concluded in the previous paper that the spectra of the various orders are determined primarily by dispersion, since R3, R5 and R7 cover progressively narrower period ranges entering about 225 sec, the period for minimum group velocity. This was in agreement with the well known relation between amplitude and the slope of the group velocity curve. It can be seen from Table I that with increasing order the spectra center on periods from 250-350 sec. Apparently the greater selective absorption of the shorter periods becomes an important factor in determining the spectra of the higher order mantle waves.

The relative amplitudes of the higher orders can be used to deduce the internal friction of mantle rocks. If the decay of amp-

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5. See footnote 1.

litude with distance is given by

$$A_z = A_o \frac{e^{-\gamma\Delta}}{\Delta^{1/2}}$$

where Ao is constant for a given period and γ is the absorption coefficient, a plot of ln ($A_z \times \Delta^{1/2}$) should give a straight line whose slope is γ . The average trace amplitudes of R6, R7, R8, R9, R10 and R12 for the period range 250-350 sec are listed in Table II. Average amplitudes are given for this period range rather than amplitudes for specific periods in order to minimize the effect of secondary amplitude variations that occur within a train but show no correlation from order to order. These may originate in interferences due to refraction or simultaneous arrival of two orders of mantle waves, both effects becoming more pronounced with increasing propagation paths of the higher order mantle waves.

Reference to Table II shows that the odd order mantle Rayleigh waves are consistently smaller in amplitude than the even order waves. The same phenomenon is apparent on the Pasadena seismogram. Since propagation effects can in no way account for this amplitude variation it must originate in an asymmetric radiation pattern at the source.

In Figure 3 a plot of ln ($A_z \times \Delta^{1/2}$) against Δ is presented for the period range 250-350 sec. Ordinates corresponding to odd order waves have been multiplied by a constant factor to allow for

their smaller amplitudes. It is seen that points fall on a reasonably straight line whose slope gives the value $\gamma = .0009 \text{ deg}^{-1} = .000008 \text{ km}^{-1}$. From the expression

$$\frac{1}{Q} = \frac{\gamma C T}{\pi}$$

where the phase velocity C=4.8 km/sec we derive $1/Q = 370 \times 10^{-5}$ for the internal friction of the mantle in the period range 250-350 sec. The corresponding wavelength is about 1500 km. Earlier results[6] for periods of 215 and 140 sec (wavelengths of 1000 km and 600 km respectively) gave $1/Q = 670 \times 10^{-5}$. These values are within the same order of magnitude. There is a suggestion of a decrease of internal friction with increasing period. Whether this is due to the dependence of internal friction on period or to greater penetration of the longer waves to deeper and different mantle layers is difficult to say. In view of the constancy of 1/Q between 140 and 215 sec, the latter alternative is favored.

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6. See footnote 1.

DISCUSSION

For periods under 400 sec the new data discussed in this paper is in excellent agreement with our previous results. With the use of a one layer approximation it was shown that the dispersion was consistent with the known increase of shear velocity with depth in the mantle.

Several values of group velocity for periods between 400 and 480 sec are determined for the first time in this study (see Figure 2). Rather than plotting as a continuation of the trend of the group velocity curve for periods under 400 seconds, these points indicate that the group velocity begins to level off for periods greater than 400 sec or wavelengths greater than about 2000 km. Since the depth to the core is 2900 km, the new trend of the group velocity curve suggests that wavelengths of the mantle Rayleigh waves have become sufficiently long to feel the effect of a low or vanishing shear velocity in the core.

In view of the small number of observations for periods greater than 400 sec this conclusion must be regarded as tentative. A new seismograph now in the design stage should provide highly significant data on the dispersion of mantle Rayleigh waves as well as their absorption for the long periods where the core becomes an important factor. Effects of gravity and sphericity of the earth will also become increasingly important for the longer periods.

CONCLUSIONS

Study of mantle Rayleigh waves from the Kamchatka earthquake of 4 November 1952 has resulted in additional dispersion data from R2, R4, R6, R7, R8, R9, R10, R11, R12, R13, R14, and R15. For periods under 400 seconds the group velocities are in excellent agreement with our previous observations. A few values of group velocity for periods 400-480 sec have been obtained for the first time and indicate that the dispersion curve begins to level off in this range. It is suggested that this is an effect of penetration to the core. Calculation of the internal friction from absorption of waves with periods 250-350 sec gives the value $1/Q=370 \times 10^{-5}$. This is a little more than half the value deduced in an earlier study for periods 140-215 sec.

TABLE I

Dispersion Data 4 Nov. 1952

R2 (Pasadena) $\Delta 2$=33, 450 km

Uncorrected time*	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
19:28:10	112	02:30:02	9002	3.72
19:31:00	175	02:32:52	9172	3.65
19:34:20	225	02:36:12	9372	3.57

R4(Pasadena) $\Delta 4$=73, 450 km

Uncorrected time*	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
22:22:40	320	05:24:32	19472	3.77
22:30:20	280	05:32:12	19932	3.68
22:38:20	220	05:40:12	20412	3.60

R6 (Palisades) $\Delta 6$=111, 600 km

Uncorrected time*	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
00:43:00	352	07:44:40	27880	4.00
00:51:00	340	07:52:40	28360	3.94
01:01:00	317	08:02:40	28960	3.85
01:11:00	285	08:12:40	29560	3.78
01:22:00	270	08:23:40	30220	3.69
01:33:00	262	08:34:40	30880	3.61
01:45:00	253	08:46:40	31600	3.53
01:37:00	245	08:38:40	31120	3.59
01:34:00	225	08:35:40	30940	3.61
01:31:00	200	08:32:40	30760	3.63
01:28:20	184	08:30:00	30600	3.65
01:26:00	160	08:27:40	30460	3.66

R7 (Palisades) $\Delta 7$=128, 380 km

Uncorrected time*	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
02:21:20	320	09:23:00	33780	3.80
02:41:00	270	09:42:40	34960	3.67

TABLE I (Cont.)

Uncorrected time	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
		R8 (Palisades) $\Delta 8$=151, 600 km		
03:16:40	400	10:18:20	37100	4.09
03:28:00	340	10:29:40	37780	4.01
03:40:00	330	10:41:40	38500	3.94
03:54:00	320	10:55:40	39340	3.85
04:10:00	310	11:11:40	40300	3.76
04:26:00	290	11:27:40	41260	3.67
04:41:00	240	11:42:40	42160	3.60
		R9 (Palisades) $\Delta 9$=168, 370 km		
04:52:40	335	11:54:20	42860	3.93
05:15:00	315	12:16:40	44200	3.81
05:38:00	305	12:39:40	45580	3.70
05:49:20	260	12:51:00	46260	3.64
		R10 (Palisades) $\Delta 10$=191, 590 km		
05:55:00	480	12:56:40	46600	4.11
06:02:00	420	13:03:40	47020	4.07
06:12:00	340	13:13:40	47620	4.02
06:32:20	320	13:34:00	48840	3.92
07:02:00	315	14:03:40	50620	3.78
07:28:00	290	14:29:40	52180	3.67
07:47:20	250	14:49:00	53340	3.59
		R11 (Palisades) $\Delta 11$=208, 370 km		
08:06:00	330	15:07:40	54460	3.83
		R12 (Palisades) $\Delta 12$=231, 590 km		
08:49:00	365	15:50:40	57040	4.06
09:30:00	320	16:31:40	59500	3.89
10:30:20	290	17:32:00	63120	3.67
		R13 (Palisades) $\Delta 13$=248, 370 km		
11:28:20	300	18:30:00	66600	3.73

* Clock corrections:

Pasadena +15 sec

Palisades +3 sec

TABLE I (Cont.)

R14 (Palisades) $\Delta 14$ =271, 590 km

Uncorrected time*	Period in sec	Travel time h-m-s	Travel time in sec	Velocity km/sec
12:26:00	330	19:27:40	70060	3.88

R15 (Palisades) $\Delta 15$=288, 370 km

13:10:00	355	20:11:40	72700	3.97

* Clock corrections:

Pasadena +15 sec

Palisades +3 sec

TABLE II

Palisades Amplitude Data 4 Nov. 1952

Order	Δ	Az	$\ln(A_z \cdot \Delta^{1/2})$
R6	1004°	4.5mm	4.96
R8	1364	2.3	4.44
R10	1724	1.6	4.20
R12	2084	1	3.82
R7	1156	2	4.22
R9	1516	1.4	4.00
R11	1876	1.1	3.86

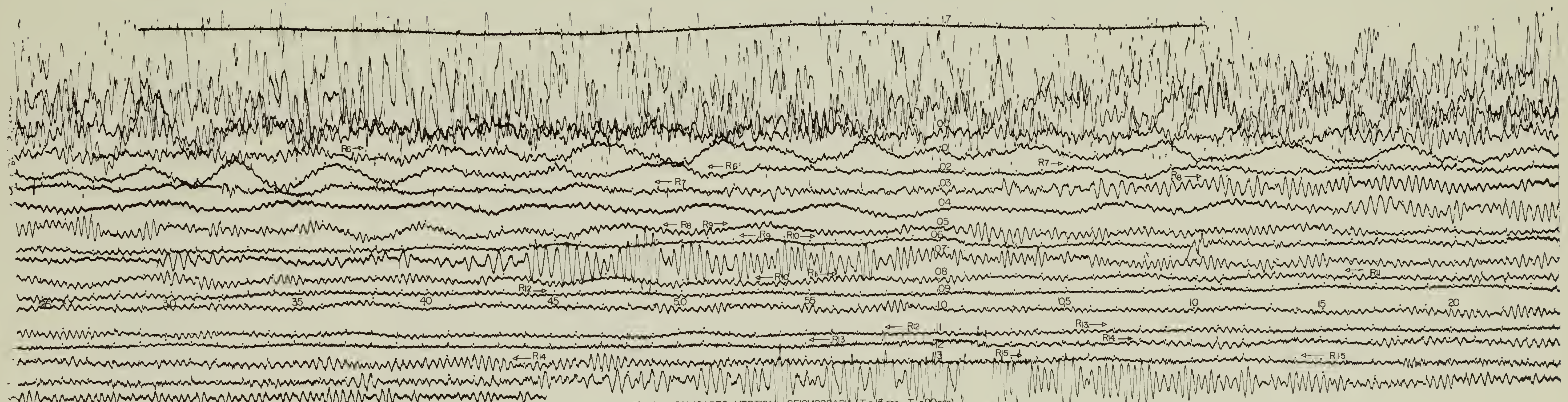

Fig. 1 PALISADES VERTICAL SEISMOGRAPH (T_o = 15 sec, T_g = 90 sec)
KAMCHATKA EARTHQUAKE 4 NOV. 1952

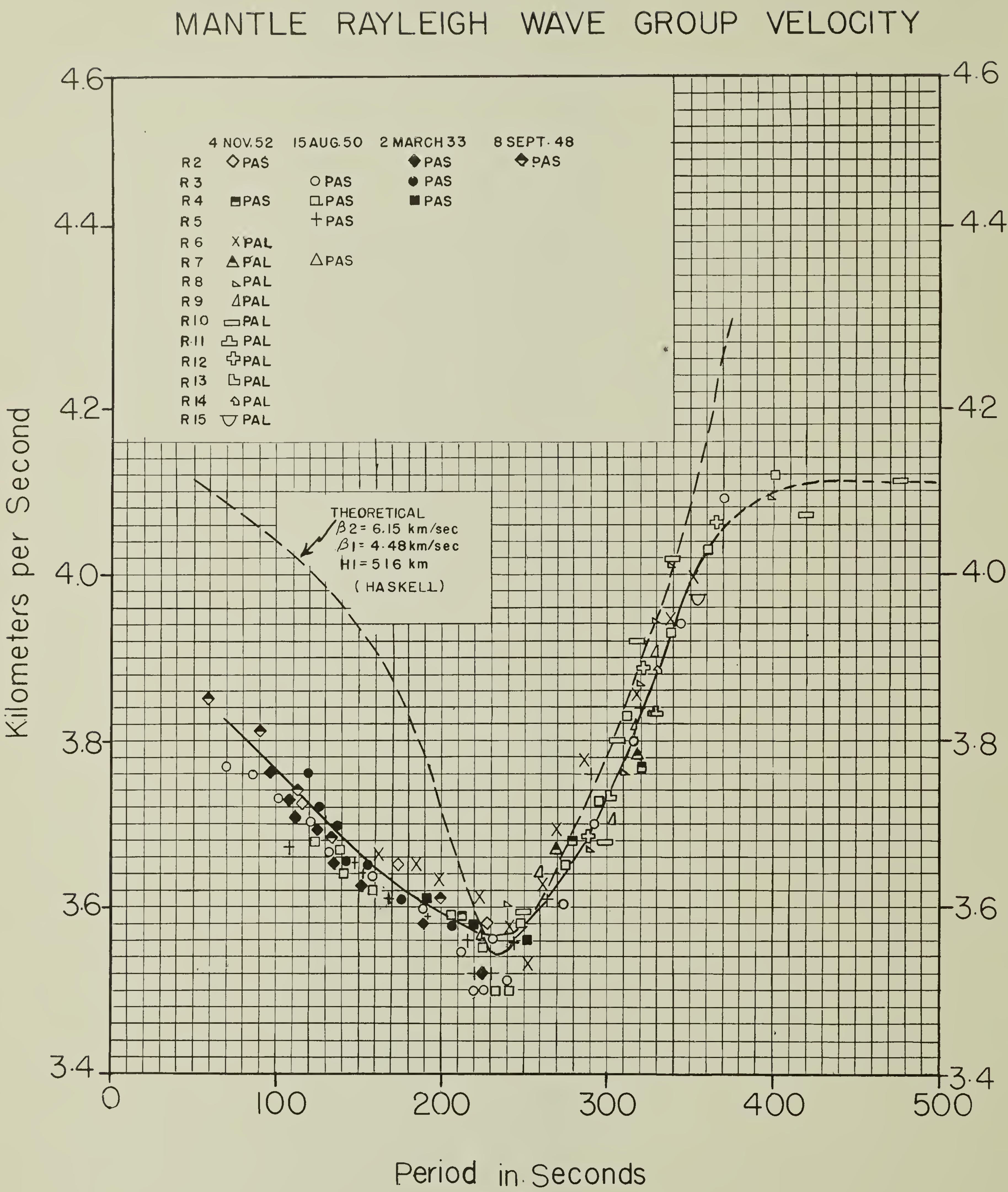

FIGURE 2. Observed group velocity for mantle Rayleigh waves compared to theoretical curve based on single layer approximation.

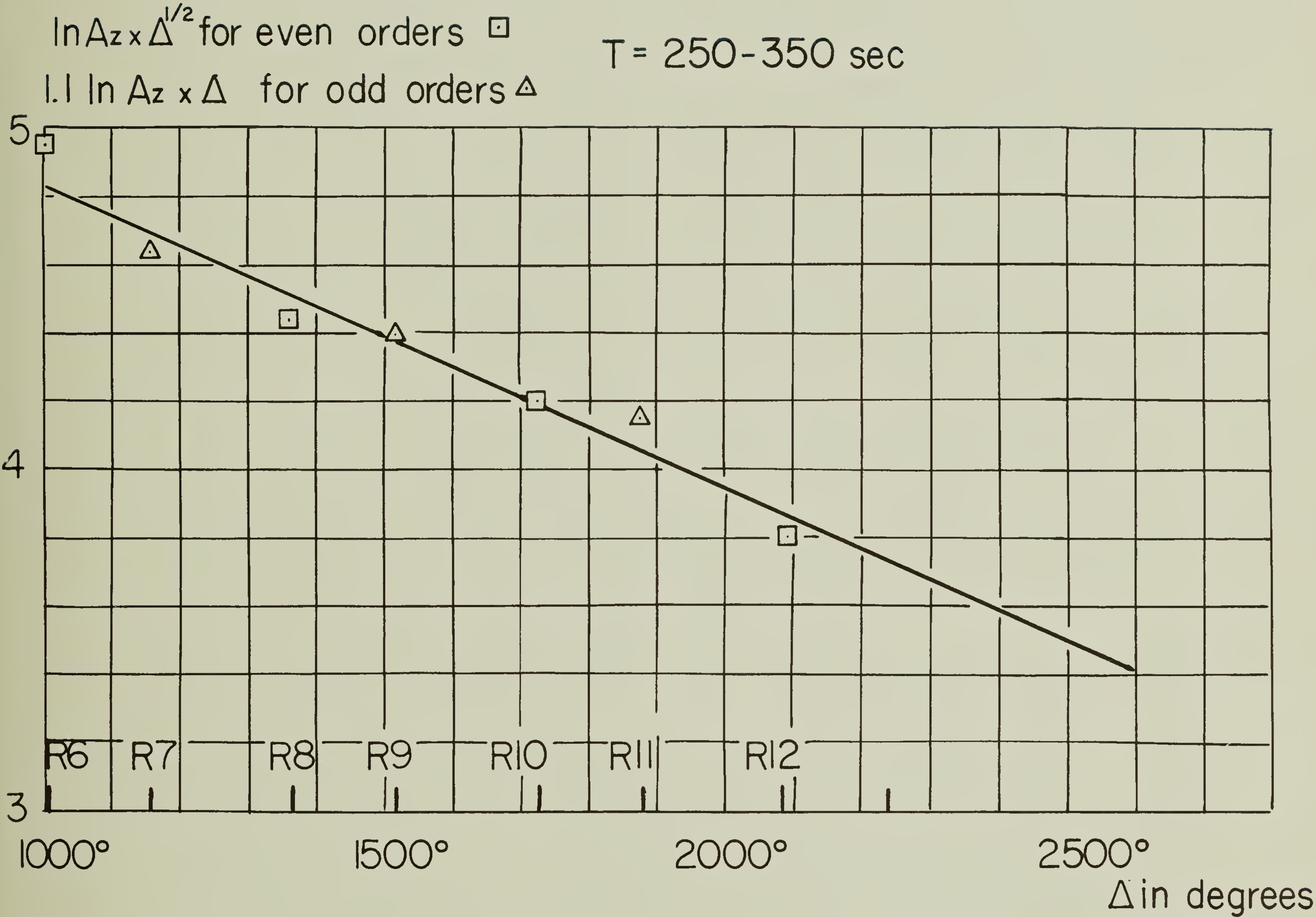

FIGURE 3. Graph of logarithm of product of trace amplitude and dispersion factor to obtain absorption constant.